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Search for missing baryon resonances via associated strangeness photoproduction

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Abstract. Differential cross-section and single polarization observables in the process $\gamma p \rightarrow K^+\Lambda$ are investigated within a constituent quark model and a dynamical coupled-channel formalism. The effects of two new nucleon resonances and of the K*(892)- and K1(1270)-exchanges are briefly presented.

PACS. 11.80.-m Relativistic scattering theory - 13.60.Le Meson production - 14.20.Gk Baryon resonances with S=0 – 24.10.Eq Coupled-channel and distorted-wave models

1 Introduction

Photoproduction of mesons appears to be a promising area to investigate issues related to the missing baryon resonances, predicted by different QCD-inspired approaches [1]. Recent works, summarized e.g. in Ref. [2], show indications on few of them. In that latter publication, we have reported on significant contributions from new S_{11} and D_{13} resonances to the process $\gamma p \rightarrow K^+\Lambda$ studied in the total center-of-mass energy range W $\equiv \sqrt{s} \approx 1.6$ GeV to 2.6 GeV, which corresponds to the baryon resonances mass region.

In this short report, we focus on the interplay between s- and t-channel contributions and the duality hypothesis.

2 Theoretical frame and t-channel issues

In order to study the kaon photoproduction on the proton, we have developed [2,3] multistep coupled channel formalisms for the reactions $\pi N \rightarrow \pi N$, $\pi N \rightarrow KY$, $KY \rightarrow KY$, and $\gamma p \rightarrow KY$. The $\pi N \rightarrow \pi N$ potential comes from an advanced version of effective Lagrangians approaches [4] using a unitary transformation method. The same method is also used to derive from effective Lagrangians the basic non-resonant $\pi N \rightarrow KY$ and $KY \rightarrow KY$ transition potentials. The direct channel $\gamma p \rightarrow K^+\Lambda$ is handled within a chiral constituent quark model [2,5] based on the $SU(6)\otimes O(3)$ broken symmetry, with the starting point being the low energy QCD Lagrangian [6]. The four components for the photoproduction of pseudoscalar mesons based on the QCD Lagrangian are:

$$\mathcal{M}_{fi} = \mathcal{M}_{seagull} + \mathcal{M}_s + \mathcal{M}_u + \mathcal{M}_t \qquad (1)$$

The first term in Eq. (1) is a seagull term. It is generated by the gauge transformation of the axial vector A_μ in the QCD Lagrangian. The second and the third terms correspond to the s- and u-channels, respectively. The last term is the t-channel contribution and contains two parts: *i)* K^+ exchange; *ii)* K*- and K1-exchanges. In our previous investigations [2,7], the dynamics of our models were partially based on the duality hypothesis, according to which, at any given energy one could use *either* the s-channel resonance prescription *or* the t-channel Regge pole description, provided that we sum over an *infinite* number of terms. An approximation to this idea and widely discussed in the literature [8], is to express the physical scattering as a series of s-channel resonances plus a general background. In those works, we had adopted this approximation, given that our approach allows us to take into account individual contributions from all known nucleon resonances in the first and second resonance regions, and treat as degenerate higher mass resonances. However, with the advent of data at high energies (W $\geq$ 2.4 GeV), it is desirable to find out how well higher mass resonances are handled and if there is need to include t-channel resonances. If so, we ought to study the drawback of such treatment on the missing resonances issues.

3 Results and discussion

We have extended the formalism presented in Ref. [2] to embody the t-channel K*- and K1-exchanges [9].

The fitted data base contains 1029 data points released recently: differential cross-sections from SAPHIR [10], recoil-Λ polarization from JLab [11] and GRAAL [12], as well as polarized beam asymmetry from GRAAL [12]. Those data

Table 1. Reduced χ^2s for the reaction mechanism configurations, as explained in the text.

Configuration	a	b	c
$\chi^2_{d.o.f}$	1.83	3.48	5.25

span the following angular and energy ranges in the phase space: $18^\circ \leq \theta_K^{c.m.} \leq 162^\circ$, 0.912 GeV $\leq E_\gamma^{lab} \leq$ 2.575 GeV, corresponding to the center-of-mass energy range 1.6 GeV $\leq$ W $\leq$ 2.4 GeV. At this stage of our study, differential cross-section data from JLab [13] and LEPS [14] have not been included in the fitted data base in order to avoid possible confusion between t-channel effects and consequences of inconsistencies among different data base, as, for example, discussed in Refs. [2,15].

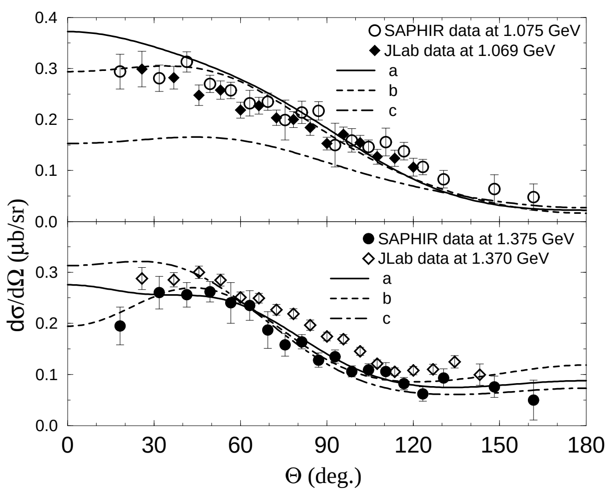

Fig. 1. Differential cross-section for the reaction $\gamma p \to K^+ \Lambda$ as a function of the outgoing kaon angle in the center-of-mass frame. The curves are: a) full model (full curves), b) full model but with t-channel K* and K1 contributions switched-off (dashed curves), c) full model, but with contributions from the new 3^{rd} S_{11} and D_{13} resonances swicthed-off (dotted-dashed curves). The curves in the upper box are for $E_\gamma^{lab} = 1.075$ GeV and in the lower one for $E_\gamma^{lab} = 1.375$ GeV. Data are from SAPHIR [10] and JLab [13].

In order to make clear the respective roles played by t-channel contributions and the new resonances, we have performed minimizations for three configurations with respect to the reaction mechanism, namely, **a)** full model: it includes all known nucleon and hyperon resonances, t-channel contributions from the exchange of K*(892) and K1(1270), as well as contributions from new S_{11} and D_{13} resonances. In the subsequent two configurations, the following contributions have been *swicthed-off*: **b)** K*- and K1-exchanges; **c)** new resonances.

In Figs. 1-3 the results of those three configurations are compared with the data around $E_\gamma^{lab} = 1.075$ GeV and 1.375 GeV, which correspond to the total center-of-mass energy W $\approx$ 1.7 and 1.9 GeV, respectively. Because of lack of space, here we single out results at only two energies, which are in the mass region of the new resonances. This choice is also related to the fact that the GRAAL [12] data are limited to $E_\gamma^{lab} \leq 1.5$ GeV.

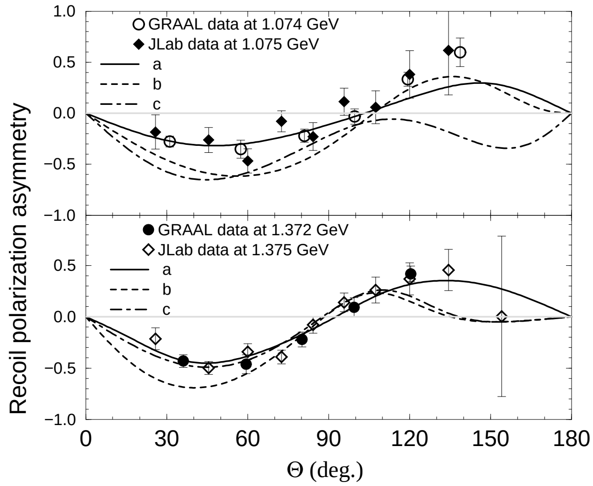

Fig. 2. Same as Fig. 1, but for recoil Λ polarization asymmetry. Data are from GRAAL [12] and JLab [11].

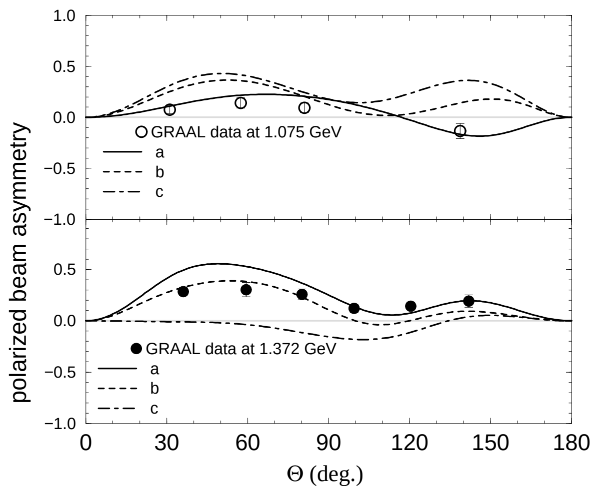

Fig. 3. Same as Fig. 1, but for polarized beam asymmetry. Data are from GRAAL [12].

Results for the differential cross-section of the reaction $\gamma p \to K^+ \Lambda$ are depicted in Fig. 1, where the JLab data [13] (not fitted) are also shown. Figures 2 and 3 embody results for single polarization asymmetries for recoil-hyperon polarization ($\gamma p \to K^+ \overrightarrow{\Lambda}$) and polarized beam ($\overrightarrow{\gamma} p \to K^+ \Lambda$).

The full model (full curves) leads to a $\chi^2_{d.o.f}$ of 1.83 (Table 1), and the extracted mass and width for the two new resonances are: $S_{11}(M = 1.820$ GeV, $\Gamma = 240$ MeV) and $D_{13}(M = 1.920$ GeV, $\Gamma = 160$ MeV). The full model gives a reasonable account of the whole fitted data base.

Table 2. Sensitivity of the investigated observables to the contributions from the t-channel (TC) K*- and K1-exchanges, and from the two new resonances (NR), corresponding to the configurations b) and c), as explained in the text. The most significant angular regions per energy are given in columns 3 to 6.

		$E_\gamma^{lab} = 1.075$ GeV		$E_\gamma^{lab} = 1.375$ GeV	
Observable	Switched-off	forward hemisphere	backward hemisphere	forward hemisphere	backward hemisphere
a) Cross-section	TC	$\leq 40°$	-	$\leq 30°$	-
	NR	30° to 90°	-	$\leq 40°$	-
b) Recoil asymmetry	TC	30° to 90°	-	20° to 50°	-
	NR	30° to 70°	$\geq 130°$	-	$\geq 130°$
c) Beam asymmetry	TC	30° to 60°	130° to 150°	-	-
	NR	30° to 60°	130° to 150°	30° to 90°	90° to 120°

Removing the t-channel resonances (dashed curves) and refitting the data, increases the $\chi^2_{d.o.f}$ by almost a factor of 2 (Table 1). In Fig. 1, the extreme forward angle data are better reproduced in the absence of t-channel contributions. This is not the case for data at higher energies (W $\geq$ 2 GeV), as expected from the duality hypothesis. Finally, minimization within the configuration **c)**, which embody no new resonances, leads to a deterioration of the $\chi^2_{d.o.f}$ by about a factor of 3 (Table 1). Switching-off the t-channel resonances or the new nucleon resonances produces significant effects on the investigated observables in various angular regions, depending on the incident photon energy. Those features appearing in Figs. 1-3 are summarized in Table 2.

4 Conclusions

Among the three observables reported here, t-channel contributions show the largest effects in the recoil-Λ polarization. The new resonances introduced here produce noticeable features on all three observables in a rather broad range of phase space. Those features are not mimicked by the t-channel resonances studied here, showing that the s-channel resonances embodied in our approach satisfy to a large extent the duality requirements. The extracted Mass and width values for those resonances are S_{11}(M = 1.820 GeV, Γ = 240 MeV) and D_{13}(M = 1.920 GeV, Γ = 160 MeV). Those values are compatible with findings from other works, namely, for S_{11} Refs. [2,5,16] and for D_{13} Refs. [2,15,17].

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